

# PM Challenge 2007

---



## Systems Engineering Processes In Principle Investigator Missions

Frank Snow, NASA/GSFC Explorers Program Office  
Dennis Lee, Systems Engineer, Swales Aerospace

# Agenda

---

- Overview/Summary
- Acknowledgements
- PI Mode missions
- Systems Engineering Definition
- Safety Compliance
- Organizational Lines of Communication
- Utilizing Existing Assets
- System Engineering Design Tools
- Requirements Management
- Configuration & Document Management
- Risk Management
- Lessons Learned
- Reliability, EEE Parts and Material Control
- Validation, Verification and Integration

# Overview/Summary

---

- Presentation Overview
  - This presentation will focus on systems engineering processes and technical management in PI mode missions.
- Summary
  - Complex scientific space flight mission are challenged to meet system requirements and top level mission success criteria.
  - The discussion will detail the systems engineering processes used to ensure PI mode mission success.
  - The presentation will discuss the technical engineering management techniques used to meet mission objectives in a satellite constellation mission.
  - Specific technical case studies will be provided to demonstrate the systems engineering techniques used in the Explorers Program Office.

# Acknowledgements

---

## **NASA/GSFC, Explorers Program Office**

Joe Bolek, Chief Engineer, Projects: THEMIS, AIM, GALEX, IBEX

## **Space Science Laboratory, University of California, Berkeley**

Peter Harvey, Project Manager, Projects: THEMIS, RHESSI, FAST

Dr. Ellen Taylor, Systems Engineer, Projects: THEMIS, ChipSat

## **Swales Aerospace, Beltsville, Maryland**

Mike Cully, Project Manager, Projects: THEMIS, Explorer Orbiter-1

Tom Ajluni, Systems Engineer, Projects: THEMIS, FUSE, WMAP

Kevin Brenneman, Systems Engineer, Projects: THEMIS, EO-1

Warren Chen , Systems Engineer, Projects: THEMIS

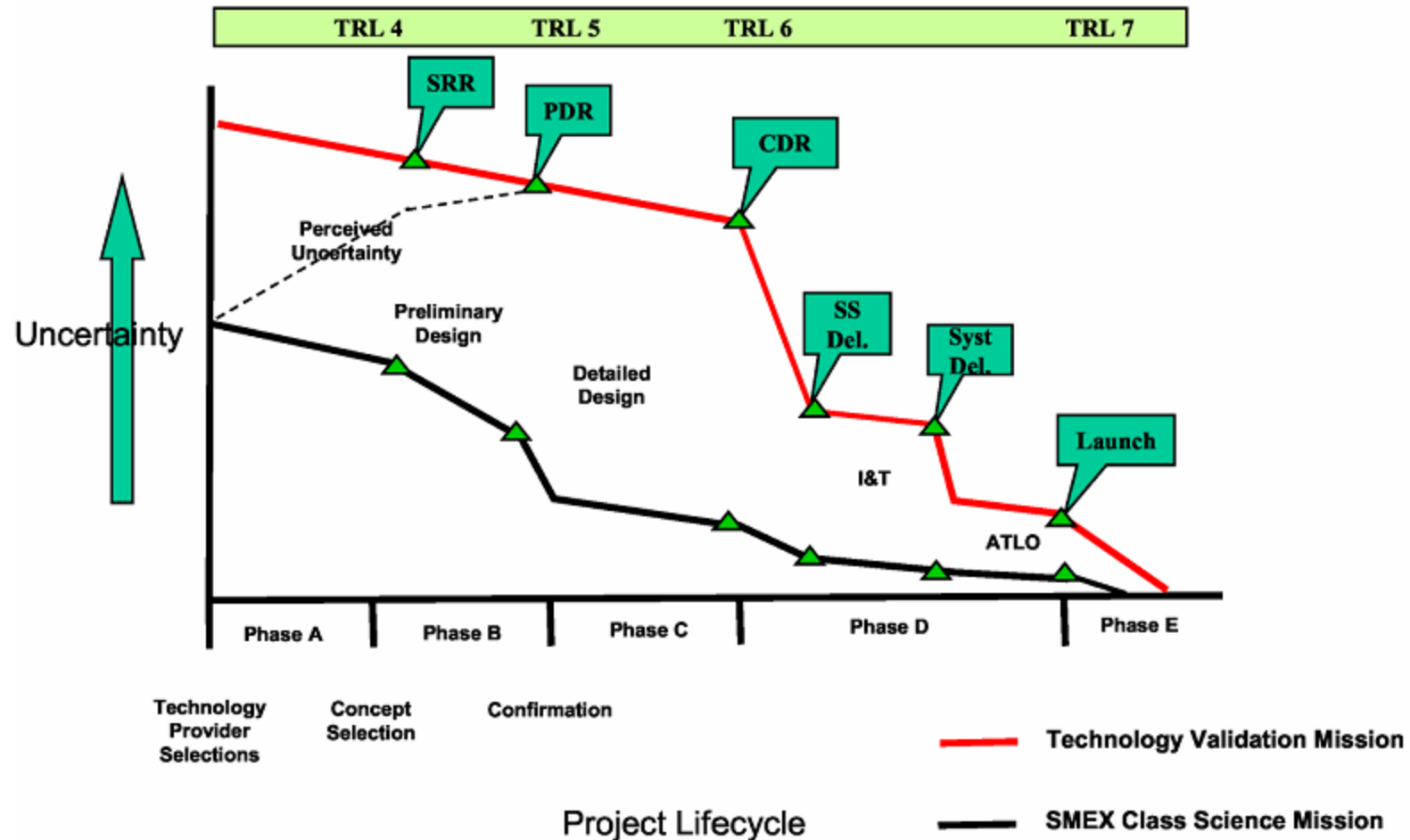
# Principle Investigator (PI) Mode Mission

---

- NASA/Goddard Space Flight Center manages PI mode mission from the Explorers Program Office for NASA Headquarters
  - Explorers is responsible for the development, fabrication, test, launch and initial orbit operations
  - Medium and Small Explorers (MIDEX, SMEX) missions are very popular in the PI scientific research community
- During the past decade, Explorers has produced highly successful, world class science mission
  - Nobel Laureate in Physics (2006), Dr. John Mather, “Legacy of COBE” includes discoveries from WMAP (Wilkinson Microwave Anisotropy Probe) MIDEX mission
  - PI defines minimum science requirements for mission success
- PI mission offer special challenges to Systems Engineering process
  - MIDEX and SMEX are cost capped missions, \$210 M and \$100 M
    - Explorers Program Office manages cost and schedule margins
    - Cost cap also drives mission schedule and technical decision process
  - PI mission require expertise in system engineering processes
    - Understanding of systems engineering process is fundamental to mission success
    - Minimal redundancy with MIDEX and no redundancy on SMEX missions
  - Explorers mission begin with elements at relatively low Technology Readiness Levels
    - Payload instrument can start at TR 4, which is technology under laboratory development
    - Lower technology levels adds technical risk and management challenges to mission development

# Risk/Uncertainty with (PI) Mode Mission

- Comparison of uncertainty (risk) between SMEX and Space Technology (ST) technology demonstration and validation missions



# Definition of Systems Engineering

---

- Systems Engineering is the application of diverse technical processes to achieve specific objectives and goals
- Technical processes include:
  - Identification and quantification of system goals and requirements
  - Assess system design safety
  - Creation of alternative system designs
  - Performing design trades
  - Selection of optimal design
  - Implementation of baseline design
  - Verification of system design and interfaces
- Systems Engineering works in concert with technical and project management
  - Optimal project decisions consider alternative designs utilizing trade studies and developed in recursive manner
  - Risk management becomes a fundamentally important during design, implementation and test verification
  - Cost effective decisions are made with engineering perspective and detailed technical information

# Safety Compliance

---

- “Safety First” is NASA’s slogan
- Explorers Program Office manages system safety compliance
  - NASA safety assurance is assigned to NASA organization, independent of project management
  - System Safety Implementation Plan (SSIP) identifies GSFC safety requirement
  - Launch range safety requirements satisfy the Air Force EWR 127-1
- System safety compliance is initially evaluated as part of design reviews
  - Safety Peer Review is completed before Critical Design Review
- Launch range safety is coordinated through Missile System Program Safety Plan (MSPSP)
  - Meets the requirements of EWR 127-1
  - MSPSP identifies all hazards associated with launch integration and operations
- System Engineering analysis is used to validate safety issues during integration and test
  - Analyses validate safe testing approaches for hazardous operating conditions
  - Hazard Reports are reviewed and understood to identify ways to mitigate safety concerns



# Organizations and Lines of Communication

---

- Project development and implementation is efficient with flat management organization and effective communication
- Systems Engineering effective with an established and structured project organizations
  - Project Work Breakdown Structure (WBS) for project control
  - Engineering and project documentation “tree” provides guidance during implementation
  - Organization needs to support Project Manager’s decision process with systems engineering input
- Some suggestions for more effective communications
  - Be responsible for verbal and written communications
    - Communication is successful when there is a 100% commitment to delivering the message
    - Be aware and intolerant to circular communications
  - Tell the “story”
    - Extremely effective in communicating and delivering a message
  - Storytelling varies depending on the audience
    - Ask the requestor for a format, style or example, what should the presentation, document or memo look like
    - For engineers, hierarchical presentation (mission, to system, to subsystem, to component, to subassembly) communicates technical details effectively

# Systems Engineering Design Tools

---

- Trade Studies are the tool used to develop robust designs and risk mitigation
  - Engineering trade studies balance design concepts against system requirements to achieve optimal design within cost and schedule
  - Trade studies are basic tool for risk assessment and reduction
- System analysis tools provides for project specific power and mass resource management
  - Mass and power management fundamental to project success
  - Margins are established by AIAA standards and provides management constraints for limited resources, allocation, tracking and trending
  - Resource trending identifies problem areas early in development cycle
- Subsystem models and analyses tools demonstrate design meets system performance requirements
  - Mechanical, Thermal and Attitude Control simulations are engineering tools used in system design
  - Sophisticated modeling demonstrate system capabilities and provide guidance for design decisions
- Flatsat test beds provide dual purpose system design tool for system validation, software checkout and verification testing

# Utilizing Existing Designs and Assets

---

- Heritage spaceflight designs and hardware can save significant non-recurring costs
  - Heritage hardware must meet the system or subsystem performance requirements
  - Heritage hardware must have flown on orbit or gone through qualification level environmental verification testing
  - Heritage hardware must demonstrate reliability requirements and failure free hours of operations, preferably on orbit
- System designers prefer heritage hardware, because the hardware saves engineering time, looks good on paper and in design reviews
  - Heritage hardware claims need to be independently reviewed and meet the criteria set forth above, before the hardware is acceptable
- NASA has a great deal of system support assets and infrastructure
  - Incorporating these assets into Explorer projects has saved valuable resources, has been effective and rewarding
  - NASA/GSFC environmental test facilities are easily coordinated into a project's verification test program
  - NASA Ground Network (GN) provides worldwide mission operations support
  - NASA Space Network (TDRSS) has been used for contingency operations and early orbit support
  - Deep Space Network supports planetary and higher orbit science missions

# Requirements Management

---

- Principle elements of Requirement Management
  - Formal process to establish, control and verify design and performance requirements
  - Consistency between technical requirements, cost and schedule are essential to mission success
- PI mode missions develop science and mission requirements during Phase A, Mission Concept Development Study
  - Mission demonstrates flow-down of science requirements to mission, systems and subsystem requirements
- Mission requirements are refined in Phase B with a formal set of NASA reviews, including Systems Requirements Review, Preliminary Design Review and Mission Confirmation Review
  - Confirmation Review verifies mission requirements can be met with sufficient technical, cost and schedule margin
- Systems Engineering is focal point for Requirements Management
  - Requirement Management implementation compliant with ISO or CMMI standards
  - Project level Requirements Management documented in Systems Engineering Management Plan (SEMP)
- Requirement Management includes traceability attribute
  - Flow down of top-level mission (parents) to system, subsystem (children) requirements
  - Requirements are clearly traceable to the verification methods and results

# Requirements Management, continued

- Requirement Management tools can be greatly simplified
  - Relational Requirement Management database are available in the commercial market
  - Swales and UCB implemented a simplified tool in Excel with clearly defined attributes

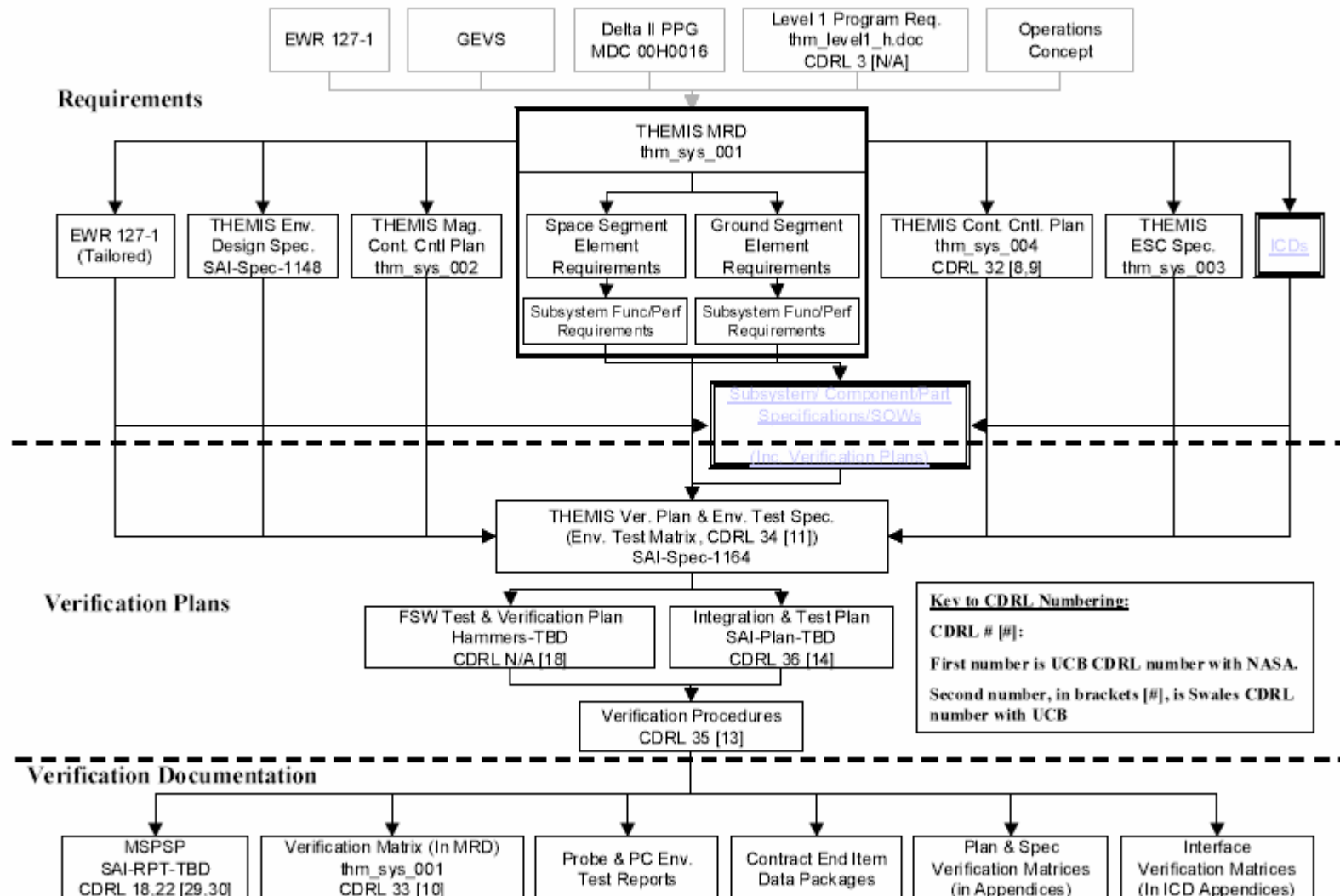
RM Attribute	Description
Organization	Identify which organization is responsible for generating this requirement
Owner+Others	Identify which individual is responsible for verifying this requirement, as well as those others with a significant effort in the verification activities.
WBS	WBS number, e.g. WBS-2.2.2 (for Probe Bus)
ID	Unique identification number, e.g. PB-356 (for Probe Bus) See Key below for a complete list
Level	Drivers (Level 1), System/Segment (Level 2), Element (Level 3), Subsystem (Level 4)
Title	Descriptive title
Statement	Requirement statement: "The ____ shall provide ____.", "The ____ shall weigh less than ____.", etc.)
Rationale	Explanation/context of requirement
Parent ID	ID of immediate higher level requirement
Source	Source of requirement (Design description document, Element Spec, analysis, best practice, etc.)
Child ID	ID of immediate lower level requirement
Status	TBD, TBR, Defined, Approved, Verified, Deleted
Verification method	Inspection / Analysis / Demonstration / Test : Description of type of test, if needed (i.e. a Verification Requirement)
Verification Documentation	Documentation in which the requirement is verified
Verification Result	Summarizes verification results
Change history	Change History, (SCN, ECR, ECP, ECN, Revision Levels)

# Configuration & Document Management

---

- CM is the glue that holds systems together
  - CM is a disciplined, rigorous approach to systems management
  - CM ties together engineering change control with technical project management
  - CM provides a formal method for subcontracts, project management and cost control
  - Simply put: no CM, no system control
- In Explorers, document management is a mechanism for controlling project data and documents
  - Explorers requires technical CM, without formal, programmatic configuration control
  - DM provides a supporting role to CM
- Baseline mission configuration established at end of Phase B, finalized at CDR
- During Phase C/D, maintenance of project CM establishes product at delivery
  - Configuration audits verify project configuration and correct documentation status
- Accurate and viable CM systems provide a true picture of project status
  - Evaluate system configuration by ECN and revision level change activity
  - External review teams can gain a quick and accurate understanding of a mission's status by auditing project CM system
- Document Management allows a deeper understanding of CM and access to technical documentation
  - Documentation Tree provides a flow between CM and technical requirements

# Project Document Tree



# Risk Management

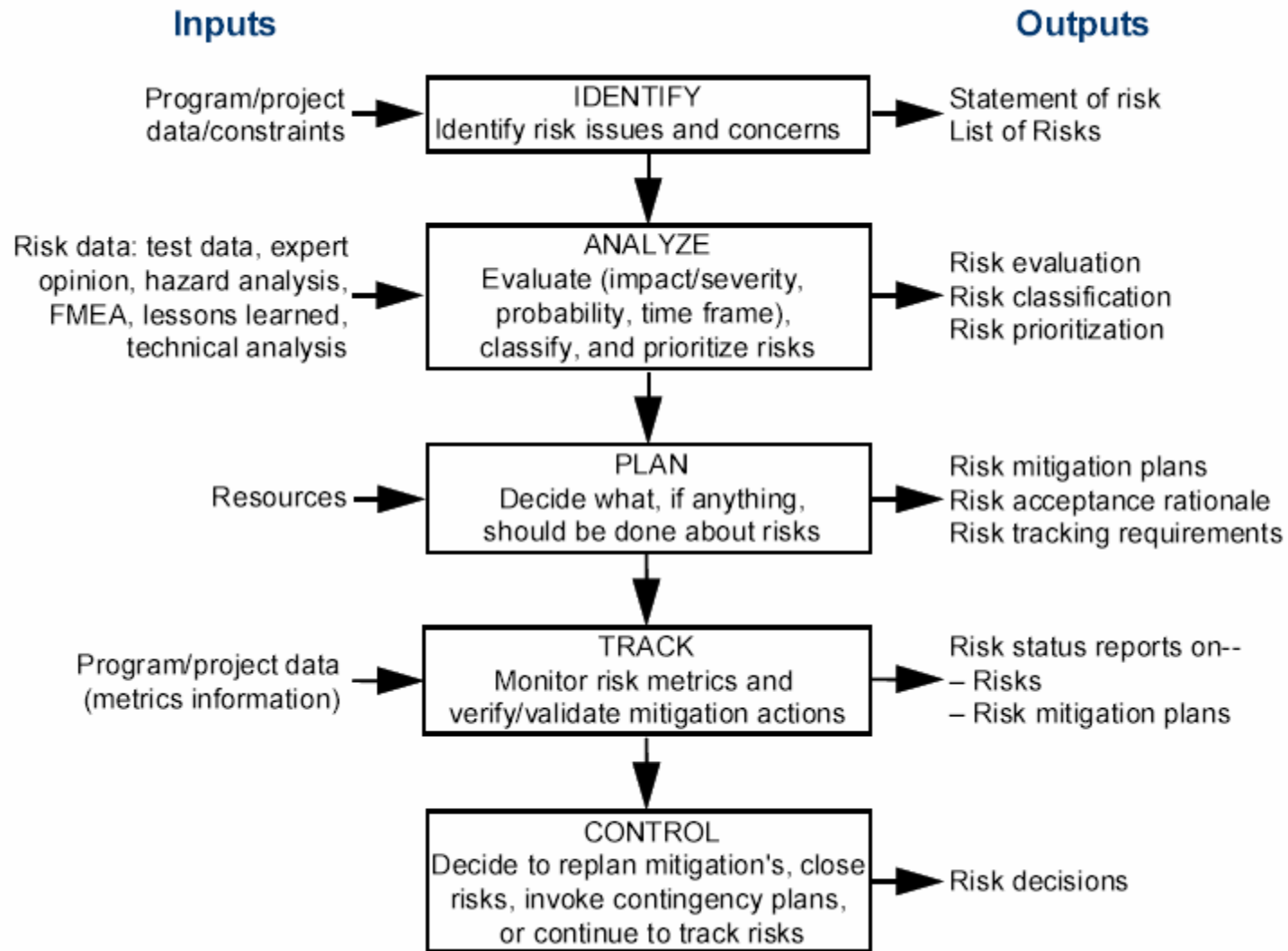
---

- Continuous Risk Management (CRM) is a process implemented early and executed throughout the project lifecycle
  - CRM is most effective when the process is part of corporate culture
  - For NASA, CRM is mandated in NPR 7120.5B
- CRM is a well defined risk management process
  - CRM sub-processes (Identify, Analyze, Plan, Track, Control) allow a dialogue and communications between technical staff and management groups
  - Continual discussions in the form of periodic risk management meeting and technical feedback form the basis for exercising CRM sub-processes
- CRM Control sub-process is easily implemented in a shared relational database
  - Swales developed PRIMX tool to provide CRM risk management process at GSFC
- CRM process implementation strategies vary depending on project and risk management objectives
  - Project tailored CRM is documented in a Risk Management Plan
  - Risk tolerance varies with project objectives, driven by mission reliability requirements
- For Project Management, there is significant value in an effective CRM system
  - Managers get visibility into issues that can represent significant cost drivers
  - Risk mitigation efforts are effective means for project control



# Risk Management, continued

---



Continuous Risk Management Process

# Lessons Learned

---

- Lessons Learned concept is a well known condition of human nature
  - “Those who don’t learn from history are doomed to repeat it.”, Winston Churchill
- Lessons Learned is a disciplined and continuous process in System Engineering and Project Management
  - Lessons Learned process needs to be incorporated throughout project life cycle
  - Using Lessons Learned during project design phase, inherent risks from past experience can be identified and mitigated before problems arise
  - Utilizing Lessons Learned in the preliminary and critical design phase provides confidence in design process
- Lessons Learned as a basic and necessary function of project risk management and risk mitigation
  - NASA Lessons Learned Information System (LLIS) is a valuable resource for project risk mitigation
  - Lessons Learned citations can validate risk mitigation approaches by providing case studies associated with similar risks and potential problems
- Implementation of Lessons Learned for SMEX mission is important, because of limited resources and to provide maximum leverage past program experiences
  - NASA Lessons Learned database is a good example of investing a small amount of resources to gain a large amount of value

# Lessons Learned, continued

- NASA LLIS validates important SMEX Phase-A proposal risks
- Helps and supports the identification of potential proposal risk and suggests risk mitigation approaches
- Leverages NASA past program and project experiences.

## NASA Lessons Learned Information System Search & Survey

<b>Risk Description</b>	<b>Total Citations</b>	<b>Relevant Citations</b>	<b>NASA LLIS Citations</b>	<b>Search String Parameters</b>
Limit Project Management experience	2	2	0904, 0919	PI Mode Project Management
S/A undersized for power	1	1	692	Solar Array Sizing
Z-dependence of Charge Resolution	0	0	N/A	GCR Charge Resolution
Shuttle manifesting and scheduling	0	0	N/A	Space Shuttle Manifest Schedule
Orbit decay & mission lifetime	0	0	N/A	Orbital Decay Mission Lifetime
Optimize mission & spacecraft design	7	4	0695, 0852, 0839, 0893	Optimize Spacecraft Design Mission
No flight experience w/ SMEX Lite bus	12	2	0637, 0725	Space Flight Qualification, Hardware Heritage
S/C rate control retrieval (failed case)	0	0	N/A	Spacecraft Rate Control
S/A shadowing in new configuration	0	0	N/A	Solar Array Shadowing
ENTICE development schedule	17	5	0479, 0533, 0594, 0619, 0968	Instrument Development Schedule

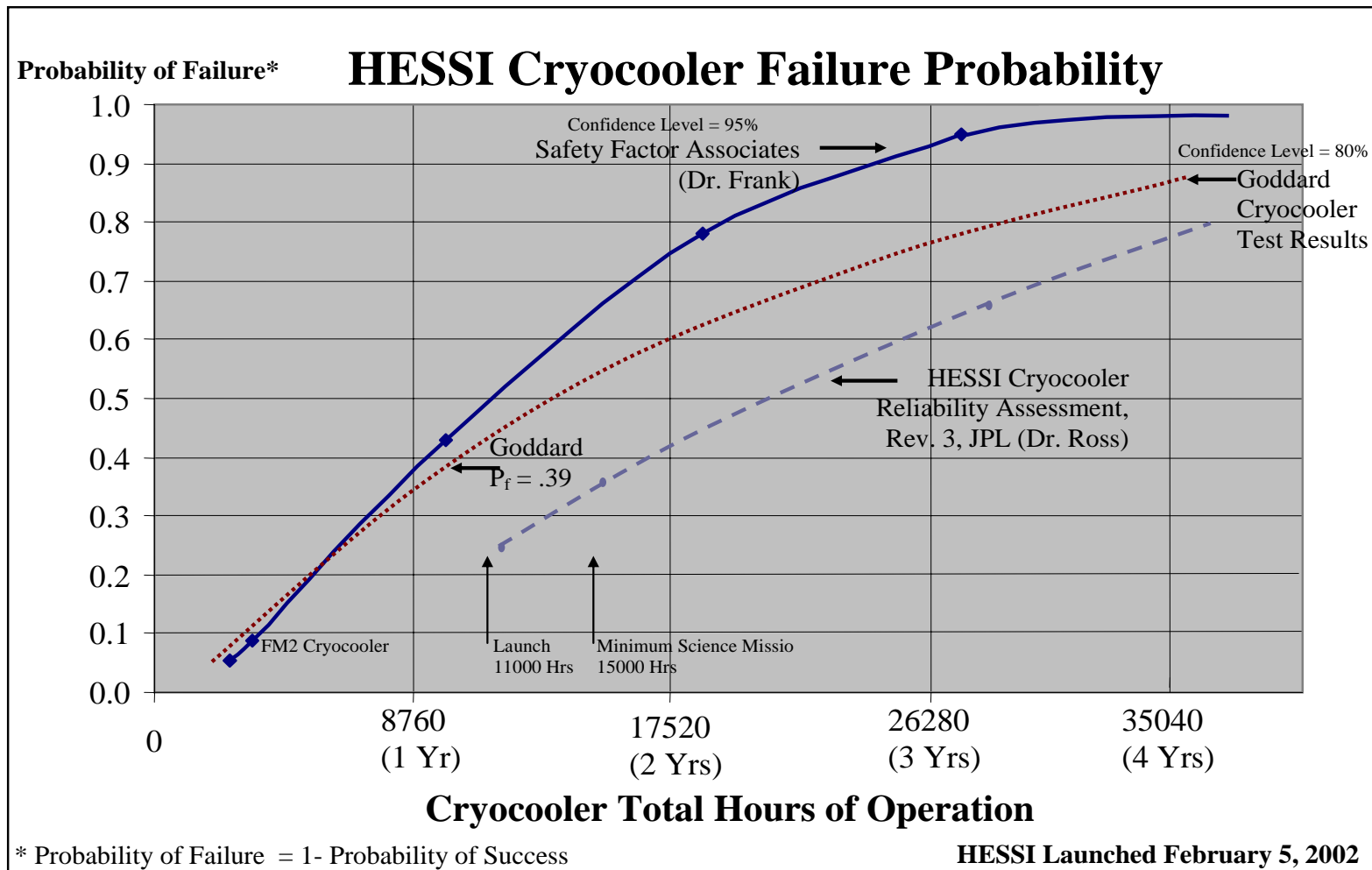
# Reliability and Material Control

---

- In Explorers, Systems and Quality Engineering manages and controls design reliability to ensure mission success
  - Reliability contributes to system's cost effectiveness and mission success
  - Risks can be managed and mitigated with proper application of system reliability
- Explorers Program Office identifies mission classification by reliability and risk
  - Explorer projects are rated Class C: medium to high risk, relatively low cost missions
  - SMEX missions are single string systems with a lower overall cost factor
  - MIDEX missions provide additional system redundancy with a higher price tag
- Electronic part reliability can be significantly increased by testing for infant mortality
  - EEE screening specifications test and qualify part types for lot acceptance
  - GSFC requires FPGA in circuit assemblies to accumulate 1000 hours of test
  - Reliability screening at component level is less common
  - RHESI cryocooler is an example process screening for "Last Man Standing"
- Material control provides the basis for reliability, quality engineering and management control
  - Explorers projects place stringent management control on Parts and Material Plans
  - EEE parts are reviewed, approved and controlled both "as designed" and "as built"
  - Material and Processes are managed space environmental compatibility and contamination control

# Reliability and Material Control, continued

- Predictions of RHESSI cryocooler assessed grim picture for mission success
  - Best case probability for meeting minimum science requirements (6 months of mission operations) was ~65%; worse case was ~30%



# Validation, Integration and Verification

---

- In systems design, there is a successive process in order to achieve mission requirements and performance checkout
  - Testing mitigates significant amounts of risk
- Validation demonstrates system concept designs can meet mission requirements
  - Design models are used to simulate basic features of systems design
  - Simulation model fidelity is important to gain confidence in design approach
  - Early structural testing with mass simulators achieves qualified flight structure
  - Structural test data is provided for launch vehicle loads interaction and system environmental (structural) test verification
- Integration is vital and necessary step for system verification testing
  - Integration testing is a form of verification, at the subassembly or subsystem level
  - Integrated testing of “first time” interfaces can show unintended design features
  - Design problems found early during integration, result in significant cost and schedule saving during system verification testing
- Verification testing is the final process to demonstrate for flight readiness
  - Levels of verification to demonstrate systems performance under flight-like conditions
  - System performance requirements are demonstrated and verified in test with margin
- End-to-End system verification ensures compatibility between spacecraft and mission operations ground system
  - Compatibility testing on the ground is mandatory on NASA missions